

Pomeron physics: an update

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Key issues in pomeron physics include whether the hard and soft pomerons are distinct objects, and whether the hard pomeron is already present in amplitudes at $Q^2 = 0$. It is urgent to learn how to combine perturbative and nonperturbative concepts, and to construct a sound theory of perturbative evolution at small x . Other questions are whether screening corrections are small, and gap survival probabilities large. Finally, do diffractive processes present a good way to discover the Higgs?

1. INTRODUCTION

The idea of the pomeron is some 40 years old. Already in its early days it was hugely successful in explaining and correlating a wide variety of reactions. In those days, the theoretical emphasis was on matrix elements being analytic functions of all their variables: s, t, ℓ, \dots (where ℓ represents orbital angular momentum). It was recognised that the positions of the singularities of the amplitudes depend only on the masses of the unphysical particles.

Nowadays the emphasis is more on perturbative QCD. Confinement is largely ignored, with the result that the singularities of the amplitudes do not depend on physical particle masses. It is urgent to learn how to reconcile the two approaches. They are not to be regarded as rivals: rather, we have to learn how to include non-perturbative effects into the perturbative formalism sufficiently to remove any conflicts with the fundamental properties of scattering amplitudes known to follow from basic principles such as unitarity.

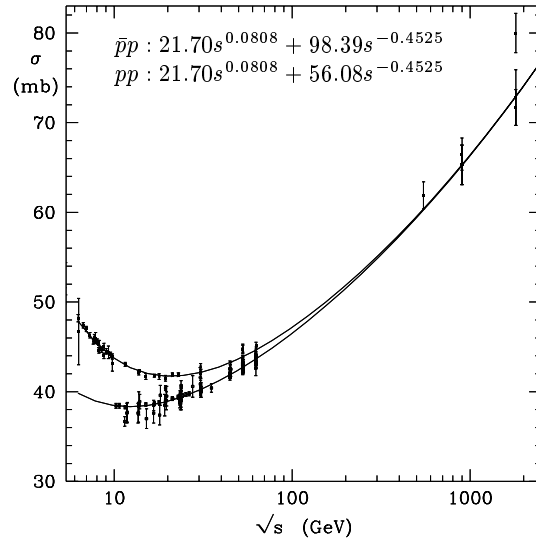


Figure 1. pp and $\bar{p}p$ total cross-sections

2. Total cross sections

Figure 1 shows data for the pp and $\bar{p}p$ total cross-sections, together with fits [1] that include the exchange of the soft pomeron and the ω, ρ, f_2 and a_2 families of particles. As is evident, there is a conflict between the two Tevatron measure-

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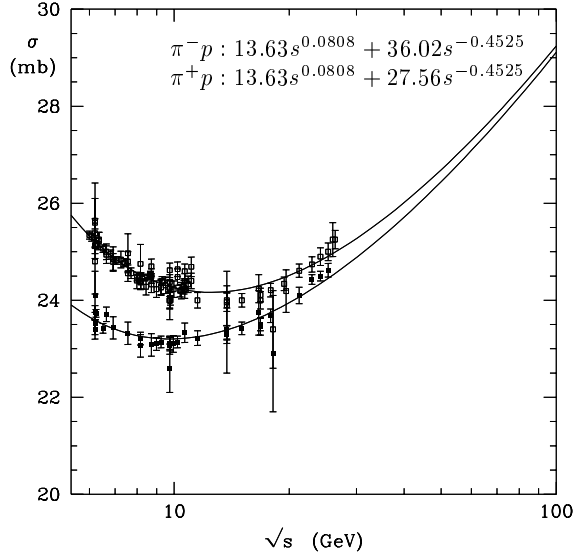


Figure 2. π^+p and π^-p total cross-sections

ments[2, 3]. I do not think it is sensible to produce a fit that goes half way between the two points. If the upper (CDF) measurement turns out to be correct, rather than the lower (E710) point, it could be an indication of a new and interesting contribution setting in at high energy, which could be confirmed at the LHC. There are some high-energy cosmic-ray data, but as Matthiae has explained at this meeting, extracting the pp cross section from air-shower data is subject to very considerable uncertainties[4].

Data for the π^+p and π^-p total cross-sections, with the corresponding fits, are shown in figure 2. They give just a hint that maybe a more rapid rise than $s^{0.08}$ is indeed appropriate. It is also interesting that the soft-pomeron coefficient is close to $2/3$ that for the pp and $\bar{p}p$ case; that is, the soft pomeron seems to couple to single quarks in a hadron, rather than to the whole hadron. This is known as the additive-quark rule.

The differences between the pp and $\bar{p}p$ cross sections, and between the π^+p and π^-p , are well described by a power close to $s^{-\frac{1}{2}}$. This is caused predominantly by the exchange of the ω family, and it may be seen in figure 3 that the intercept of that Regge trajectory is close to $\frac{1}{2}$. This figure also demonstrates the well-known fact that Regge trajectories are almost straight. We know

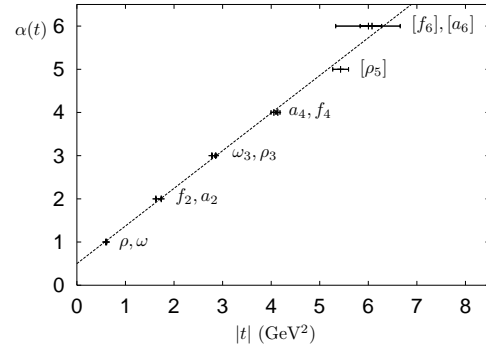


Figure 3. Four degenerate Regge trajectories: particle spins plotted against their squared masses t . The particles in square brackets are listed in the data tables[5], but there is some doubt about them. The straight line is $\alpha(t) = 0.5 + 0.9t$.

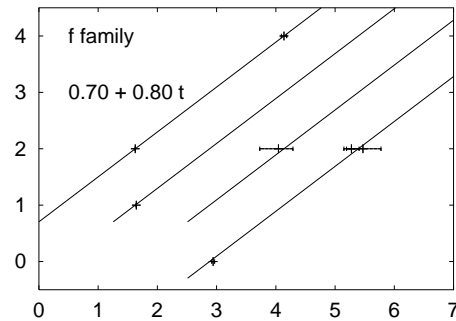


Figure 4. The f_2 family with daughter families. Only those states listed as confirmed in the data tables[5] are shown.

that they cannot be exactly straight: $\alpha_\rho(t)$ has a branch point at $t = 4m_\pi^2, 16m_\pi^2, \dots$, while $\alpha_\omega(t)$ has a branch point at $t = 9m_\pi^2, 25m_\pi^2, \dots$. The surprise is how straight they are. The figure shows also that four trajectories approximately coincide. However, this exchange degeneracy is not exact. This is seen in figure 4, which shows that the f_2 trajectory has an intercept closer to 0.7 than 0.5 . This figure also shows striking confirmation for the existence of daughter trajectories, that is trajectories spaced at integer steps below the parent. At this meeting, Pacannoni, and more particularly Dainton, have stressed that we might expect that the pomeron trajectory too

has daughters.

3. Elastic scattering

The single-pomeron-exchange contribution to pp or $\bar{p}p$ elastic scattering is[6]

$$\frac{d\sigma}{dt} = C[F_1(t)]^4(\alpha's)^{2\alpha(t)-2} \quad (1)$$

where the constant C is fixed from the magnitude of the pomeron-exchange contribution to the total cross sections and $F_1(t)$ is the proton's elastic form factor, measured in elastic ep scattering. It appears to be consistent with experiment to assume that the pomeron trajectory too is straight:

$$\alpha(t) = 1 + \epsilon + \alpha't \quad \epsilon \approx 0.08 \quad (2)$$

The value of α' is fixed at 0.25 GeV^{-2} from the data at one energy and very small t : see figure 5a. The form (1) then fits the data at that energy out to larger values of t , as is seen in figure 5b. This confirms that the effect of the proton wave function is correctly taken into account with $F_1(t)$. This again is a reflection of the apparent fact that the pomeron couples to single quarks, like the photon[9]. As $F_1(t)$ is raised to the fourth power in (1), the fit is sensitive to the choice of form factor, and it is something of a surprise that the electromagnetic form factor, which corresponds to $C = -1$ exchange, should also be applicable for $C = +1$ pomeron exchange.

Once α' is fixed, the form (1) fits well at all energies. In particular, it correctly predicts the shrinkage of the forward peak in the differential cross section: see figure 6.

A similar form, with appropriate changes of form factor, also fits other elastic scattering processes, for example[6] $pd \rightarrow pd$. A further success is the process $\gamma p \rightarrow \rho p$, for which one obtains[11] a zero-parameter fit by introducing vector meson dominance. The result is compared with ZEUS data[12] in figure 7.

4. Controversy: how large is the screening?

Nicolescu told us at this meeting that what we know as the Froissart-Martin bound:

$$\sigma^{\text{Tot}} < \frac{\pi}{m_\pi^2} \log^2 s \quad (3)$$

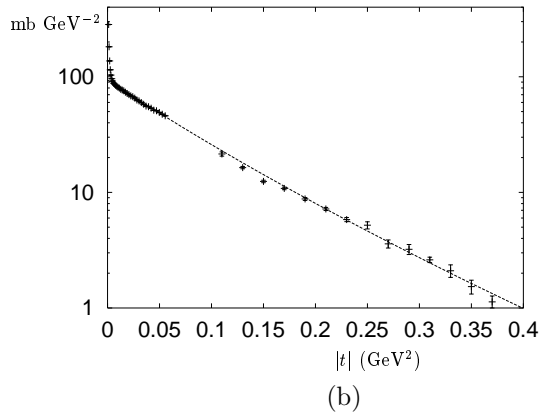
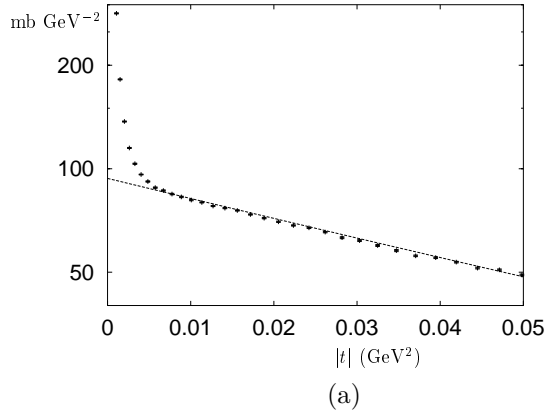


Figure 5. pp elastic scattering data at $\sqrt{s} = 53 \text{ GeV}$ from the CERN ISR[7, 8] with (a) the fit that determines the value of α'_P and (b) the fit extended to larger values of $|t|$

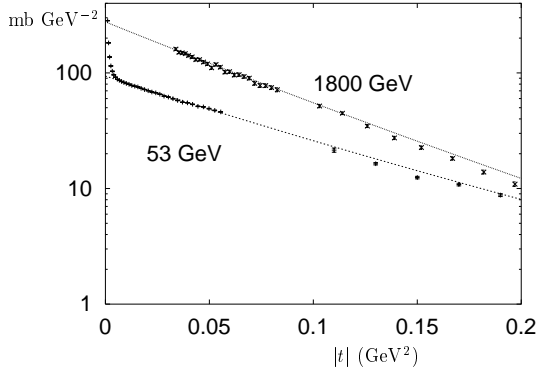


Figure 6. The $\sqrt{s} = 53$ GeV data from figure 5 plotted together with data[10] at $\sqrt{s} = 1800$ GeV, together with (1) corresponding to $\alpha'_P = 0.25$ in (2)

was first proposed by Heisenberg[13] as long ago as 1952. The bound is obviously in conflict with a fixed power behaviour, so the power $s^{0.08}$ can only be an effective power, which must reduce as s increases. There are two divergent views about this. Donnachie and I believe that the “bare” pomeron yields a power just a little greater than 0.08, and that at $t = 0$ there is, at present energies, a relatively small negative screening contribution from the exchange of two pomerons. Almost everybody else disagrees: the double exchange is large and the bare-pomeron power is significantly greater than 0.08. For example, at this meeting Kaidalov proposed the value 0.25.

As was shown by Mandelstam[14], the coupling of two pomerons to a hadron is not through the same quark. Thus the notion that the screening is large at $t = 0$ does not accord naturally with the additive-quark rule, and with what we have seen is the simplest explanation of the elastic scattering data. Also, there is some direct evidence[15] that, in the diffractive process $pp \rightarrow \Lambda\phi Kp$, the pomeron does couple to a single quark. Further, a large screening contribution would make the effective power process-dependent, and not universally close to 0.08, as various data suggest. Similar remarks apply to the effective slope α' at small t . A further piece of evidence, still to

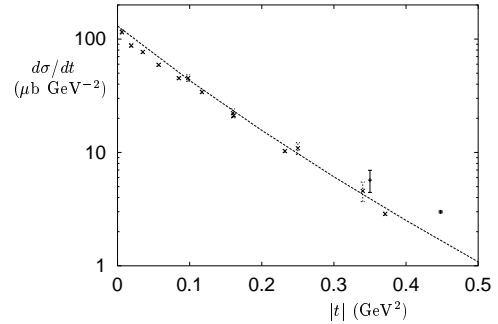


Figure 7. ZEUS data[12] for $\gamma p \rightarrow \rho p$ with the pomeron-exchange prediction. The lower t data are at $\sqrt{s} = 71.7$ GeV and the higher- t data at 94 GeV.

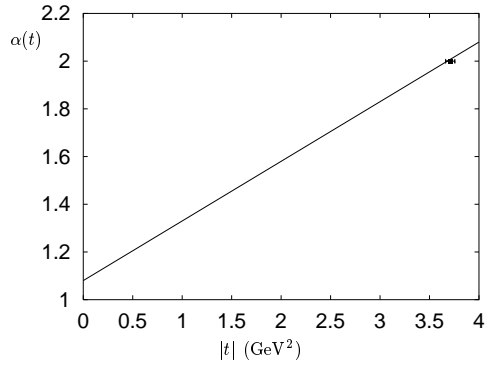


Figure 8. 2^{++} glueball candidate[?], with the line $\alpha(t) = 1.08 + 0.25t$

be confirmed, concerns the question of whether there are particles on the pomeron trajectory. It is widely agreed that, if there are, they are glueballs. There is a 2^{++} glueball candidate[16] at exactly the right mass to lie on a pomeron trajectory of slope $\alpha' = 0.25$ GeV $^{-2}$ and intercept close to 1.08: see figure 8.

5. Dips

Figure 9 shows the ISR data with the very striking dips in pp elastic scattering. These data are reminiscent of the intensity distributions in optical diffraction, and this has led some people to speculate that there will be further dips at larger values of t . However, although the anal-

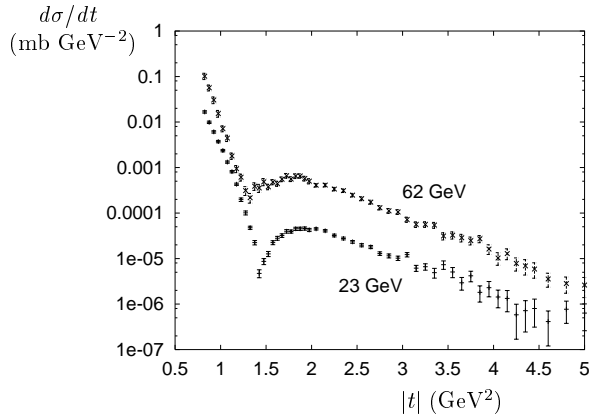


Figure 9. pp elastic scattering data at larger t (CHHAV collaboration[17]). The 62 GeV data are multiplied by 10.

ogy with diffraction may be valid at small values of t , and therefore the dips seen in scattering on nuclear targets may be regarded as diffractive, for larger values of t the analogy is not all that close. In fact, it is actually quite difficult to achieve a dip. The reason is that the rather general requirements of analyticity and crossing impose on an amplitude a close relationship between its phase and its variation with energy. If we parametrise its energy dependence as an effective power, $T(s, t) \sim s^{\alpha_{\text{eff}}(t)}$, then, depending on the C-parity of the exchange responsible for this, the phase of the pp amplitude is

$$\begin{aligned} -e^{-\frac{1}{2}i\pi\alpha_{\text{eff}}(t)} & \quad C = +1 \\ -ie^{-\frac{1}{2}i\pi\alpha_{\text{eff}}(t)} & \quad C = -1 \end{aligned} \quad (4)$$

As is seen in figure 9, the dip has steep sides and moves inwards as s increases. Hence if we fix t at some value in the dip region, the amplitude varies rapidly with energy. So models in which the amplitude is taken to be pure-imaginary for all t are not consistent with (4).

It is natural to try to achieve a dip through interference between single-pomeron and two-pomeron exchange. Although we cannot calculate the strength of two-pomeron exchange, we do know that it yields a cut in the complex angular momentum plane. If the pomeron trajectory

is (2). the cut trajectory is

$$\alpha_{PP}(t) = 1 + 2\epsilon + \frac{1}{2}\alpha't \quad (5)$$

With $\epsilon = 0.08$ and $\alpha' = 0.25$, the phases associated with the single and double exchanges are

$$\begin{aligned} -e^{-\frac{1}{2}i\pi\alpha_P(t)} &= -0.4 + 0.9i \\ -e^{-\frac{1}{2}i\pi\alpha_{PP}(t)} &= -0.02 + 1.0i \end{aligned} \quad (6)$$

So if there is destructive interference between the imaginary parts of the two contributions, we still need something else to help cancel their real parts. Donnachie and I suggested[18] that the extra term was 3-gluon exchange, and therefore predicted that the dip would not be present in $\bar{p}p$ elastic scattering, because 3-gluon exchange is $C = -1$ and therefore contributes with opposite signs to pp and $\bar{p}p$. This prediction was subsequently confirmed[19], and it is now fairly generally accepted [20, 21] that to the left of the dip the dominant exchange is $C = +1$, while to the right it is $C = -1$.

Figure 10 shows pp data at t -values beyond the dip. As is seen, for $\sqrt{s} > 27$ GeV the data are almost energy-independent and behave as t^{-8} . This is what is calculated[23] from perturbative triple-gluon exchange at large $|t|$ to lowest order in the QCD coupling (figure 11).

It is interesting to ask whether the energy-independence at large t survives at higher energies. In particular, if there really is a BFKL pomeron, replacing the gluons in figure 11 with it might give a dramatic *rise* with increasing energy. Again a question for the LHC.

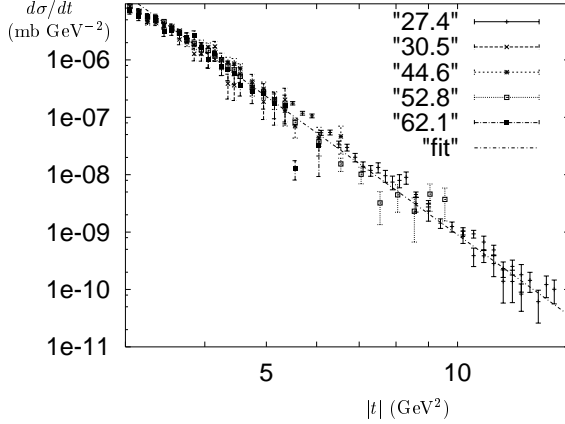


Figure 10. pp elastic scattering data[17, 22] at the largest available t ; the line is $0.09 t^{-8}$

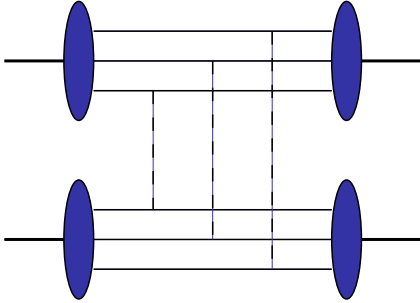


Figure 11. 3-gluon exchange

6. Diffraction dissociation

Figure 12 shows data for diffraction dissociation, $pp \rightarrow pX$, where the final-state proton has lost only a small fraction ξ of its initial momentum. Experimentalists often quote the value of the “total” diffractive cross section, which is $d^2\sigma/dtd\xi$ integrated over some range of t and of $\xi = M_X^2/s$. It is evident from the figure that there is a resolution problem: ξ cannot really be negative. There is uncertainty about the correction for this. Also, most of the cross section comes from small M_X (and small t), and so the answer is sensitive to the choice of lower limit in the integration.

Apart from these experimental uncertainties,

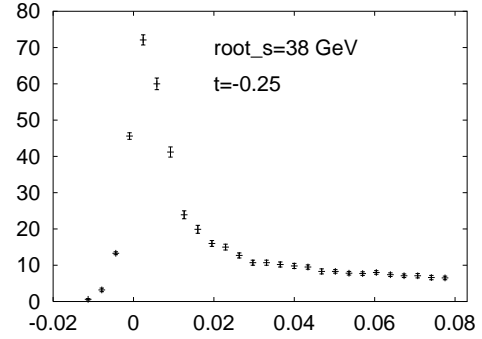


Figure 12. CHLM data[24]: $d^2\sigma/dtd\xi$ plotted against $\xi = M_X^2/s$

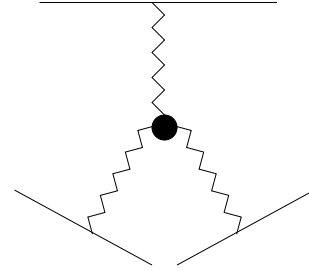


Figure 13. Triple-reggeon mechanism

there are serious theoretical ones. It is often assumed that the mechanism is that of figure 13, the triple-pomeron diagram. However, unless M_X is large, say greater than 50 GeV, there is also a significant contribution from the diagram where the upper pomeron is replaced with a nonleading exchange. And if M_X is too small, less than a few GeV, the mechanism is not applicable at all. Again, unless ξ is very small, there are significant contributions from either of both of the lower pomerons being replaced with a nonleading exchange ($f_2, \omega, \pi \dots$). Fits to data are very model-dependent, but they always find that these contaminations from nonleading exchanges are large[25, 26]. An example is the H1 fit to their data[27] for real-photon-induced diffraction dissociation, figure 14.

At this meeting, Goulianos has suggested that there are problems with the conventional Regge interpretation of the data for the total diffractive

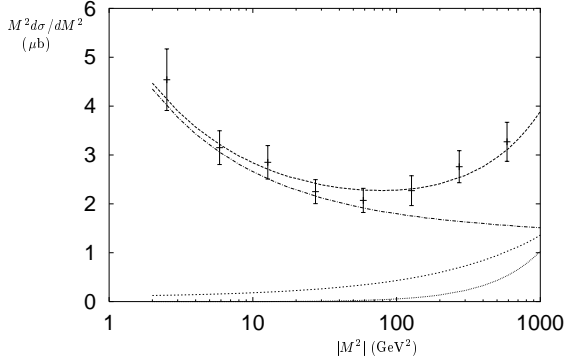


Figure 14. The diffraction dissociation cross section $M_X^2 d\sigma/dM_X^2$ in photoproduction at $W = 187$ GeV [27]. The lines, from the bottom upwards, represent fits to the reggeon-exchange contribution, its interference with pomeron exchange, the pomeron exchange, and the total.

cross section. For the reasons I have given, I do not believe that there are yet grounds to worry. We need more detailed data, which unfortunately have not been provided yet by the Tevatron experiments. There are, as yet, no data at higher energies as good as the ISR data, an example of which is shown in figure 12.

7. Controversy: how many pomerons?

I turn now to hard processes. The data show clearly that the soft pomeron is not enough, and something else is needed. We call this the “hard pomeron”, though there are different views on what this is. However, even without this question, there is a more basic one: is it that the soft pomeron becomes progressively harder as the scale Q^2 of a reaction increases, or is the hard pomeron a separate object from the soft one?

Specifically, for the case of the small- x behaviour of the structure function $F_2(x, Q^2)$, the first of these two alternatives is

$$F_2(x, Q^2) = f_0(Q^2)x^{-\epsilon_0} + f_1(Q^2)x^{-\epsilon_1} \quad (7)$$

with both ϵ_0 and ϵ_1 fixed. Here ϵ_1 is the soft-pomeron power, $\epsilon_1 \approx 0.08$, and the data need [28] ϵ_0 to be a little greater than 0.4. As Q^2 increases, the ratio $f_0(Q^2)/f_1(Q^2)$ increases. This is the alternative that Donnachie and I prefer, because we take seriously the prejudice developed 40

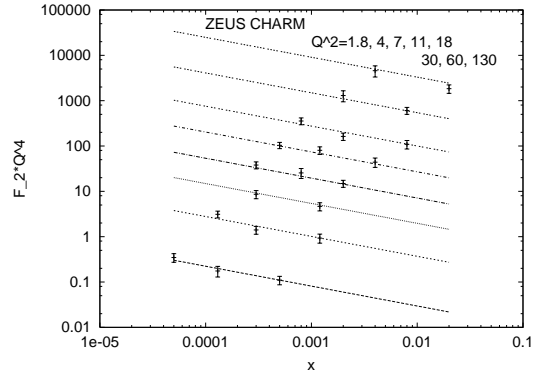


Figure 15. Data [29] for the $Q^4 F_2^c(x, Q^2)$, fitted [11] to $f_0(Q^2)x^{-\epsilon_0}$ with $\epsilon_0 = 0.44$

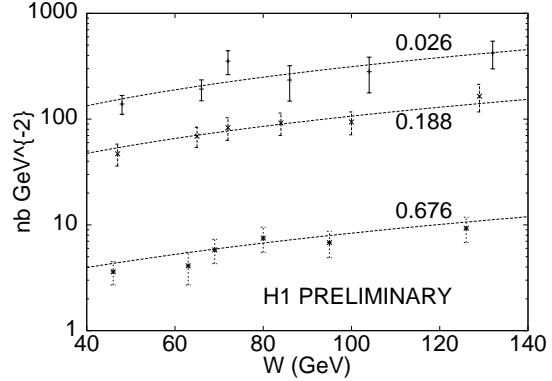


Figure 16. The differential cross section for $\gamma p \rightarrow J/\psi p$

years or so ago that the positions of singularities in the complex angular momentum plane should not vary with Q^2 .

Almost everybody else adopts the alternative approach, that at small x

$$F_2(x, Q^2) = \mathcal{F}(Q^2)x^{-\epsilon(Q^2)} \quad (8)$$

where $\epsilon(Q^2) = \epsilon_1$ at $Q^2 = 0$ and rises to ϵ_0 , or even larger, at large Q^2 . This rise in the value of $\epsilon(Q^2)$ is supposed to be caused by perturbative evolution; however, there is a growing realisation that we do not understand the theory of perturbative evolution at small x . Martin gave some hint of this in his talk.

The ZEUS data for the charm component of F_2 , that is the part F_2^c of F_2 for which the vir-

tual photon is supposed to have been absorbed by a charmed quark, seems to provide striking confirmation[30] of the fixed-power approach: see figure 15. However, these data need to be treated with some caution, because to extract them a large extrapolation in p_T is needed. Nevertheless, the same approach gives an excellent description[11] of the process $\gamma p \rightarrow J/\psi p$, both the total cross section and the t dependence. The fit shown in figure 16 corresponds to the amplitude

$$T(s, t) = i \sum_{i=0,1} C_i F_1(t) s^{e_i(t)} e^{-\frac{1}{2} i \pi e_i(t)} \quad (9)$$

with

$$\begin{aligned} e_0(t) &= 0.44 + 0.1t \\ e_1(t) &= 0.08 + 0.25t \end{aligned} \quad (10)$$

$F_1(t)$ is again the Dirac form factor of the proton target, and C_0 and C_1 are both independent of s and t . It is interesting that these data lead to a hard-pomeron trajectory slope that is somewhat smaller than that of the soft pomeron.

For $\gamma p \rightarrow J/\psi p$ the ratio of C_0 to C_1 needs to be about $\frac{1}{10}$. A similar fit to $\gamma p \rightarrow \rho p$ needs this ratio to be much smaller, mainly because the soft-pomeron term f_1 is much larger. If we extend the fit to $\gamma^* p \rightarrow \rho p$, the ratio must grow with Q^2 .

The form (7) provides[28] an excellent fit to the small- x data for $F_2(x, Q^2)$. With an additional term $f_2(Q^2)x^{0.45}$ corresponding to f_2 exchange, the fit extends up to $x = 0.07$ or more, and it covers all the available range of Q^2 , from real photons to $Q^2 = 2000 \text{ GeV}^2$. Figures 17 and 18 show data at large and small Q^2 , while figure 19 shows data for real photons.

8. Key question: is the hard pomeron present at $Q^2 = 0$?

The lower curve in figure 19 shows the prediction for $\sigma^{\gamma p}$ that we made[1] before the HERA data were available, and including only soft-pomeron and f_2 -exchange terms. The highest-energy data point is the new ZEUS measurement, which now agrees well with the H1 point. The upper line is the extrapolation to $Q^2 = 0$ of the small- Q^2 ZEUS data of figure 18. This extrapo-

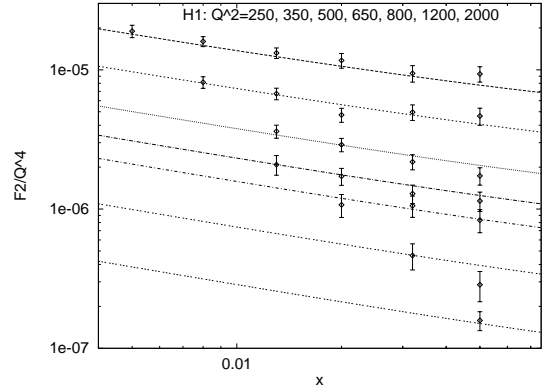


Figure 17. Large- Q^2 data for $F_2(x, Q^2)$ with $x < 0.07$

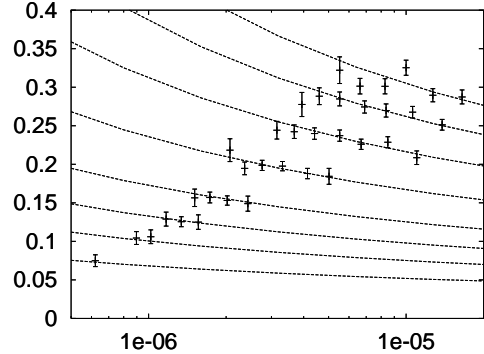


Figure 18. Small- Q^2 data, ranging from $Q^2 = 0.045$ (lower points) to 0.3 GeV^2 (upper points)

lation includes a hard-pomeron component. Because the data in figure 18 extend down to very small Q^2 , this extrapolation would be rather reliable, were it not for the fact that the data in figure 18 do not show the systematic errors, which are as large as $\pm 10\%$ at the lowest Q^2 . So we cannot be sure whether a hard pomeron component is present at $Q^2 = 0$ or not, though there is more than a hint that it may be.

There is a similar uncertainty with the interpretation of the data for $\sigma^{\gamma\gamma}$ from LEP. De Roeck has told us at this meeting that the L3 collaboration favours the presence of a hard-pomeron compo-

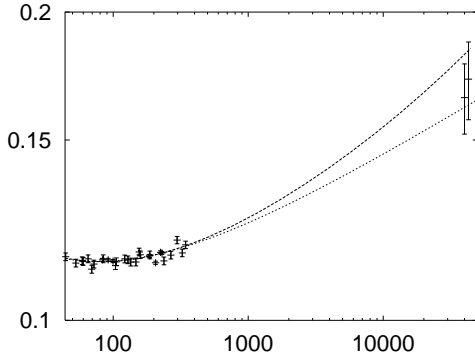


Figure 19. Data for $\sigma^{\gamma p}$. The upper line is an extrapolation of the data of figure 18 to $Q^2 = 0$.

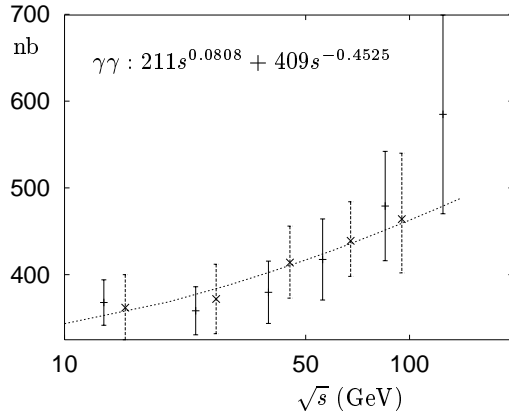


Figure 20. $\gamma\gamma$ total cross section with the fit obtained from factorisation

nent at $Q^2 = 0$, while OPAL does not. Figure 20 shows the fit obtained by applying factorisation to the $\sigma^{\gamma p}$ and σ^{pp} curves in figures (19) and (1), with no hard-pomeron component. The highest-energy data point from L3 possibly does call for such a component to be added.

This is an important question. Is the hard pomeron already present at $Q^2 = 0$, or is rather generated by perturbative evolution? If it is there already at $Q^2 = 0$, since it is not seen in the $\bar{p}p$ total cross section presumably it arises because the photon has a pointlike component. But occasionally the quarks in a proton are very close together, so a hard-pomeron component should

also be present in σ^{pp} . Will it be large enough to be identified at the LHC?

9. Hard diffraction

The present situation concerning hard diffraction is a confusing one. The two HERA experiments agree that the effective pomeron intercept in hard-diffractive events is significantly higher than 1.08, $\alpha_{\text{eff}} \approx 1.2$, and that the gluons provide 80 to 90% of the momentum of the pomeron. Goulianos told us at this meeting that the Tevatron experiments conclude that the gluon momentum fraction is no more than 50%, and that they find a dramatic breakdown in factorisation.

There are theoretical uncertainties. First, if a diffractive event is defined as one with a very fast proton, the theory is quite well defined. But in practice much of the data is rather obtained by requiring just a large rapidity gap, for which the theory is much less certain. We have heard Khoze describe an apparently-successful calculation of gap survival probabilities, but the theory of this is deeply uncertain. Even apart from this difficulty, until it becomes possible to compare data from HERA and the Tevatron where both triggers are on a very fast final-state proton (or antiproton) there is a worry that we may not be comparing like with like, if what goes down the beam pipe is not the same. Again, there are uncertainties in extracting the gluon component of the pomeron structure function; the HERA experiments have obtained rather different outputs using different analyses. Further, one should not expect factorisation, given that α_{eff} is not equal to the soft-pomeron value. Whatever is the explanation for this, whether it be BFKL, a combination of hard and soft pomerons, important screening effects, or any other, all would agree that factorisation should break down. Nevertheless, it is surprising that the breakdown is so dramatic. For example, Goulianos and Santoro have told us that the Tevatron cross section for W production accompanied by a very fast proton or antiproton is nearly an order of magnitude smaller than expected, and diffractive dijet production has similar problems.

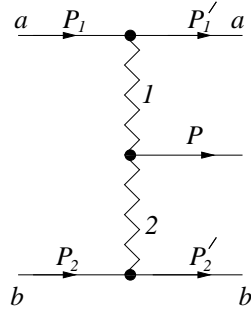


Figure 21. Exclusive central Higgs production

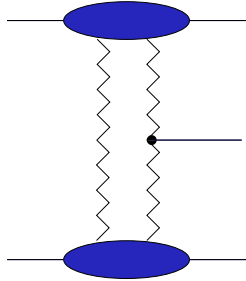
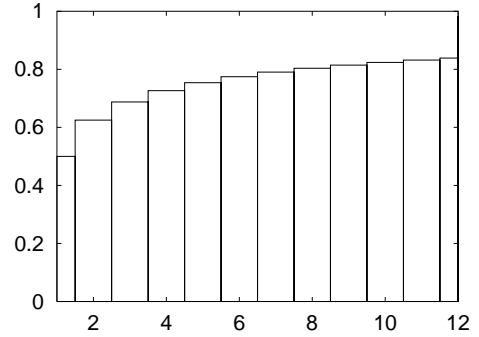


Figure 22. Screening correction to figure 21

10. Diffractive Higgs production

It was suggested 10 years ago[31] that diffractive Higgs production should be feasible: see figure 21. This is the process $pp \rightarrow pHp$, with both final-state protons very fast. There have been various calculations that model the coupling of the two pomerons to the Higgs. Most[32, 33], though not all[34, 35], predict a cross section large enough for it to have been suggested[36] that this exclusive reaction might be the best way to discover the Higgs particle. This is because the momenta of the two final protons may be measured very accurately, so that the missing mass, presumed to be that of the Higgs, may be determined very accurately, and in consequence the signal-to-background ratio is much enhanced. The reason for this is as follows. The best way to detect the Higgs is through its decay to a heavy quark-antiquark pair. The background is direct production of the pair, not through a Higgs. The ratio of the amplitudes for signal compared with

Figure 23. Partial sums of the series expansion of (11) at $x = 1$ plotted against the number of terms

the background is similar[37] to that in the case of ordinary, nondiffractive production. However, because of the much better mass resolution, the background is integrated over a much smaller mass range.

The difference between those who predict a large cross section and those who do not lies in the estimate of the screening correction to figure 21: see figure 22. If you believe, as I do, that screening in the pp total cross section is small, then it is hard to believe that it will reduce the diffractive Higgs production by a factor of more than 2, say. But those who believe in large screening believe that the suppression is an order of magnitude or more.

11. Perturbative evolution

There has been a growing realisation that we do not understand the theory of perturbative evolution at small x . While there are various ideas on the subject, there is no agreement whatever[38]. The problem lies in the perturbative expansion of the DGLAP splitting function $P(z)$, whose terms are singular at $z = 0$. In lowest order, there are terms α_S/z , and the Mellin transform has terms α_S/N . In higher orders the singularities at $z = 0$ or $N = 0$ become worse. For small- x evolution, we need the splitting function for small values of z or N , so the expansion parameter is large and the expansion is illegal.

It is not necessarily a comfort to ignore this problem and find that the perturbation expansion stabilises after a few terms. As a simple example, consider the expansion of the function

$$f(x) = 1 - \sqrt{1-x} \\ = \frac{1}{2}x + \frac{1}{8}x^2 + \frac{1}{16}x^3 + \frac{5}{128}x^4 + \dots \quad (11)$$

at $x = 1$. The result is shown in figure 23. After 10 terms, each additional term in the expansion contributes less than 1%, but nevertheless the sum is nearly 20% below the correct value.

So, finding that higher-order terms in a perturbation expansion are small does not necessarily indicate that we are near to the right answer. We should not trust the expansion for values of x and Q^2 where it leads to a rapid variation of $F_2(x, Q^2)$. That is, while it might possibly be correct that the hard pomeron is generated by evolution, this cannot be trusted numerically until Q^2 becomes large.

The known connection[39] between DGLAP and BFKL tells us that $P(N)$ is not singular at $N = 0$, even though each term in its expansion is singular. In fact $P(N)$ behaves something like $f(x)$ in (23) with x set equal to α_S/N : the partial sums become more and more singular at $N = 0$ as we add terms, but the function itself is not singular at $N = 0$.

My guess is that $P(N)$ has no relevant singularities at all. In that case[40], a fixed power $f_0(Q^2)x^{-\epsilon_0}$ of x remains a fixed power under evolution, and the evolution determines the behaviour of $f_0(Q^2)$ at large Q^2 . that is, the hard pomeron is already present at $Q^2 = 0$ and the evolution presumably enhances its relative importance as Q^2 increases.

12. The main issues

- Is screening in soft processes large or small?
- Are the hard and soft pomeron distinct objects?
- Is a hard pomeron already present at $Q^2 = 0$? Will it be seen in the pp total cross section at the LHC?
- Are there glueballs on pomeron trajectories?
- How straight are the trajectories?

- Can we calculate gap survival probabilities?
- Do screening corrections leave $pp \rightarrow p$ Higgs p large enough to see?
- Will pp elastic scattering at large t be the same at LHC energies as at ISR energies?
- **Can we construct the theory of perturbative evolution at small x ?**
- *We need to combine perturbative and nonperturbative concepts — evolution and analyticity.*

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